EFFECT OF PROCESS PARAMETERS ON SURFACE ROUGHNESS OF NICKEL BASED ALLOYS IN WEDM

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ABSTRACT

In contrast to conventional machining process, WEDM may be proved more economic and efficient in precise machining of wide range of materials ranging from die steel to the high temperature resistance super alloys. In this study, the effect of WEDM process parameters like peak current (Ip), pulse on time (Ton), pulse off time (Toff) and servo voltage (V) on the surface roughness has been considered while machining of Nimonic 90 and Monel 400 using Taguchi's method. Using Taguchi's L18 orthogonal array, process parameters were investigated for surface roughness. Analysis of variance shows that Ton and Ip are highly significant process parameters for surface roughness.

KEYWORDS

WEDM, Nimonic-90, Monel-400, Taguchi method, Surface roughness.

1. INTRODUCTION

Nickel based super alloys are growing class of exotic materials which is potentially used in the manufacturing of components for aerospace engine in gas turbine compartments and other applications such as sub marine equipment's, nuclear reactors, petrochemical plants, aircraft gas turbines components, medical equipments e.g. dentistry uses, prosthetic devices and orthopaedic application, etc. [1-2]. Aerospace industries are the main consumer of nickel based alloys because they possess excellent mechanical and chemical properties at very high temperature.

Nickel based alloys may contain the constituents of chromium, aluminium, titanium, cobalt, molybdenum and other elements in varying quantity to give their outstanding high temperature strength and extreme toughness which create difficulties during machining and resulting in development of very high cutting forces [3-4**]. **Conventional machining of these material forms a built layer on cutting tool face, which results poor surface integrity and higher crater wear involving several surface defects such as, material pull-out/cracking, surface drag, tearing surface, etc. [5-9]. These surface defects significantly lower the fatigue life of nickel based aero-components.

WEDM is a non-conventional machine and proved more efficient and economic for machining complex and difficult geometries in high hardness and high heat resisting materials with high accuracy. Several attempts have been made on EDM and WEDM. Machining of Hastelloy–X with EDM, Pulse on time (Ton) is the main process parameter affects the surface integrity of the work surface [10]. The most influential factor on MRR is peak current (Ip) and duty factor. High value of Ip is suggested for obtaining high MRR during the EDM of Inconel 718 with hollow

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tools [11]. Machining of Inconel 718 using EDM with a copper electrode, Taguchi technique is used to analysis the effect of each process parameter, i.e., peak current (Ip), Ton, gap voltage and duty cycle on machining performances such material removal rate (MRR), electrode wear rate (EWR), radial over cut (RoC) and half taper angle. Ip significantly affects the MRR and Ton significantly affects the EWR [12].

Singh et al. [13] investigated the effect of WEDM process parameters namely, Toff, Ton, servo voltage (SV), Ip, wire feed rate (W_F) and Wire tension (W_T) on MRR of hot die steel (H-11) with one variable at a time approach. It is concluded that MRR is directly decreases with increase in Toff and SV and increases with increase in Ton and Ip. Kumar et al. [14] reported the effect of four inputs WEDM parameters such as, Ip, Ton, Toff and SV and modeled for two performance characteristics, i.e., MRR and surface roughness (SR). The effect of process parameters is analysed using response surface graphs. Result showed that surface finish may be enhanced efficiently using single trim cut at low discharge energy with appropriate wire off-set value. Jangra et al. [15] presented an experimental study of rough and trim cutting operation of Nimonic 90 with three different materials, i.e., Die steel, Tungsten carbide composite and Monel 400 in WEDM. Results suggested that surface characteristics may be improved using single trim cut with optimal machining parameters and correct wire offset, irrespective the high discharge energy of rough cut. Using Gray–Taguchi method, WEDM process parameters of Incoloy 800 super alloy are optimised for multiple machining performances, i.e., MRR, SR and kerf [16].

Based on preliminary experiments on WEDM of Nimonic-90 and Monell 400, it is found that effective working range of pulse-on time is 106 µs to 118 µs. Beyond 118 µs at Toff below 35 µs, breakage of wire electrode occurs frequently. Effect of peak current (Ip) is noticeable only from 70 A to 160 A, therefore, an effective range of 90 A to 150 A has been selected for Ip. Similarly for SV an effective range of 30 V to 50 V has been selected that provide a noticeable variation in machining performance. In present study two Nickels based alloy Nimonic 90 (Nickel – Chromium – Cobalt alloy) and Monel 400 (Nickel - Copper alloy) are taken as work materials**.** Effect of machining parameters namely; Toff, Ton, Ip and SV are evaluated on SR in WEDM using Taguchi's design of experiment. An optimal setting of machining parameters is obtained for minimising the surface roughness in WEDM of Nickel alloys.

2. EXPERIMENTAL PROCEDURE

2.1 Experimental procedure

A 5 axis sprint cut (ELPUSE-40) WEDM is used for experimental work, manufactured by Electronic M/C Tool LTD India (Figure 1). Copper coated brass wire of diameter 0.25 mm is used. Distilled water as a dielectric fluid is used with conductivity 20 µS/cm. W_F is kept constant value of 5 m/min. Wire off set is taken at zero value. The chemical composition and mechanical properties of Nimonic 90 and Monel 400 work-piece materials used in the experiments in the form of a rectangular sheet of 12.5 mm thickness are shown in Tables 1.

Table 1: Chemical composition and mechanical properties of Nickel based alloys

Work Material	Density	Melting point	Co-efficient of Expansion	Modulus of Rigidity	Modulus of Elasticity
Nimonic 90(wt %) (Ni 60, Cr 19.3,Co 15, Ti 3.1, Al 1.4)	8.18 g/cm^3	1370^0C	$12.7\mu m/m\,^0C$	82.5KN/mm²	213KN /mm²
Monel 400(wt %) (Ni 63.47, Cu 33, Fe 2.13, Mn 1)	8.8 g/cm^3	1350^0C	$13.9\mu m/m\,^0C$	65.3 KN/mm²	115 KN/mm²

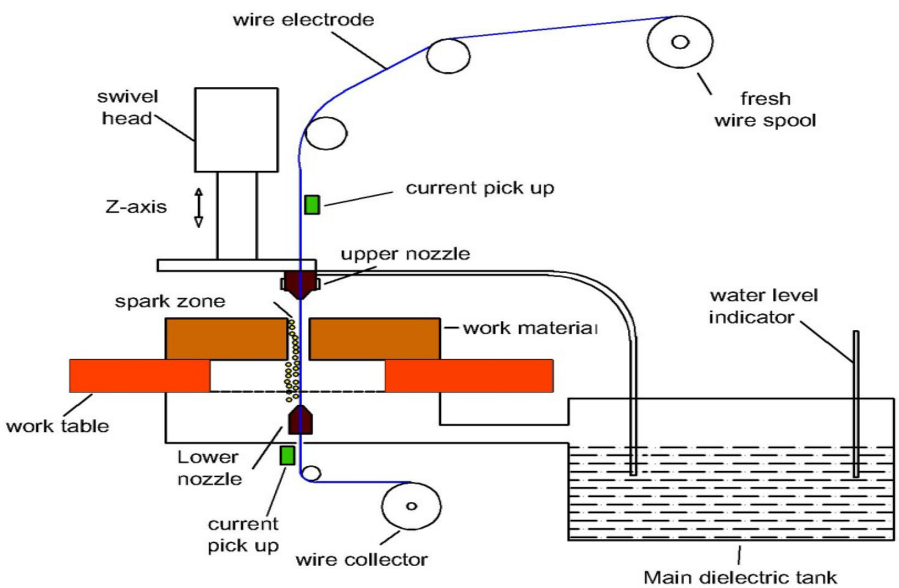

Figure1. Schematic Representation of WEDM Process

2.2. Experimentation Methodology

In present work, five process parameters have been chosen for investigation such as work materials (M), Ip, Ton, Toff, and SV. Table 2 shows the selected parameters and their levels. L_{18}, orthogonal array is selected in present work to conduct the experimentation. Experiment plan is listed in Table 3.

Table 2: Machining parameters and their levels

Symbol	Machining Parameter	Units	Level 1	Level 2	Level 3
A	Material (M)	----	Monel-400	Nimonic-90	---
B	Peak Current (Ip)	A	90	120	150
C	Pulse on Time (Ton)	μs	106	112	118
D	Pulse off Time (Toff)	μs	35	40	45
E	Servo voltage (SV)	V	30	40	50

2.3 Experimental Results

Based on the experimental layout shown in Table 3, the experiments are performed. The SR (Rmax. μm) of machined surface is measured by using the digital surface tester Mitutoyo 201P. Measured surface roughness characteristics are shown in Table 4. Residual plot for mean surface roughness are shown in Figure 2.

Residual plots are used to assess the data for the problems like non-random variation, non-constant variance, non normality and higher-order relationships. Figure 2 show that the residuals follow an approximately straight line in normal probability plot. Approximate symmetric nature of histogram referred that the residuals are normally distributed.

Table 3: Experimental layout using an L18 orthogonal array

	Machining parameters				
Exp No.	A Material type	B Peak current	C Pulse on time	D Pulse off time	E Servo voltage
1	Monel-400	90	106	35	30
2	Monel-400	90	112	40	40
3	Monel-400	90	118	45	50
4	Monel-400	120	106	35	40
5	Monel-400	120	112	40	50
6	Monel-400	120	118	45	30
7	Monel-400	150	106	40	30
8	Monel-400	150	112	45	40
9	Monel-400	150	118	35	50
10	Nimonic-90	90	106	45	50
11	Nimonic-90	90	112	35	30
12	Nimonic-90	90	118	40	40
13	Nimonic-90	120	106	40	50
14	Nimonic-90	120	112	45	30
15	Nimonic-90	120	118	35	40
16	Nimonic-90	150	106	45	40
17	Nimonic-90	150	112	35	50
18	Nimonic-90	150	118	40	30

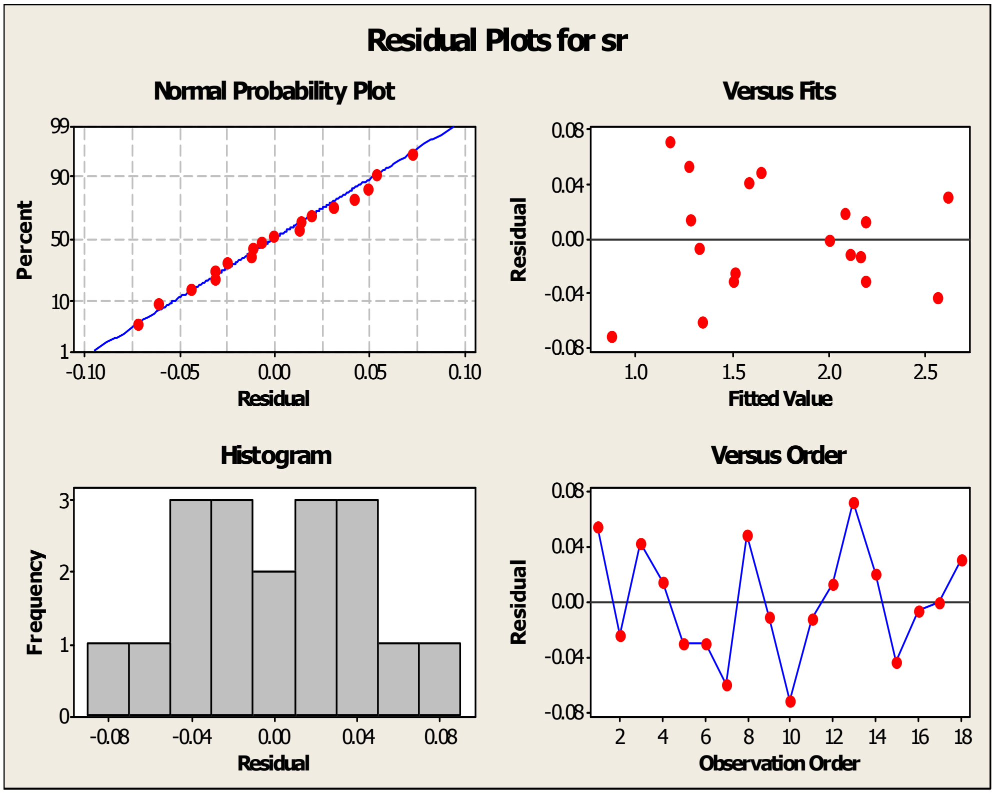

Figure 2. Residual Plot for Mean Surface Roughness

3. RESULT AND DISCUSSION

The S/N ratio may be used to measured deviation of the performance characteristics from the desired value in Taguchi method, so that the experimental results are changed into a signal to noise (S/N) ratio. The aim of using the S/N ratio is to determine the performance to develop products and processes insensitive to noise factors. There are three types of S/N ratio, i.e., lower the better, higher the better and nominal the better. In present work, lower the better is selected for SR. Table 4 shows the S/N ratio and measured mean values of SR.

S/N for lower the better

S/N ratio $\eta = 10 * \text{Log}\ (1/\sum_{i=1}^{n} \frac{1}{y_{ij}^2})$

Where n= repeated number of experiments

y_{ij} =observed machining experiment response value

Where i = 1, 2, 3,......, n   j = 1, 2, 3,......., k

Table 4: Mean value and S/N ratio of Surface Roughness

Experiment No.	**SR (µm)**	**(S/N ratio) SR**
1	1.33	-2.47703
2	1.49	-3.46373
3	1.63	-4.24375
4	1.3	-2.27887
5	1.47	-3.34635
6	2.16	-6.68908
7	1.28	-2.1442
8	1.7	-4.60898
9	2.1	-6.44439
10	0.8	1.9382
11	2.15	-6.64877
12	2.2	-6.84845
13	1.25	-1.9382
14	2.1	-6.44439
15	2.52	-8.02801
16	1.32	-2.41148
17	2	-6.0206
18	2.65	-8.46492
Average	1.747222	

The response table is used to find out the effect of each level of process parameter on SR using Taguchi method. Table 5 shows response table for mean SR.

Table 5: Response Table for Mean SR

Level	**A Material type**	**B Peak current**	**C Pulse on time**	**D Pulse off time**	**E Servo voltage**
1	1.607	1.600	1.213	1.900	1.945
2	1.888	1.800	1.818	1.723	1.755
3	**----**	1.842	2.210	1.618	1.542

Figure 3 shows the S/N ratio plot for SR. The optimum parameters combination for SR is A1B1C1D3E3 corresponding to largest values of S/N ratio for all process parameters.

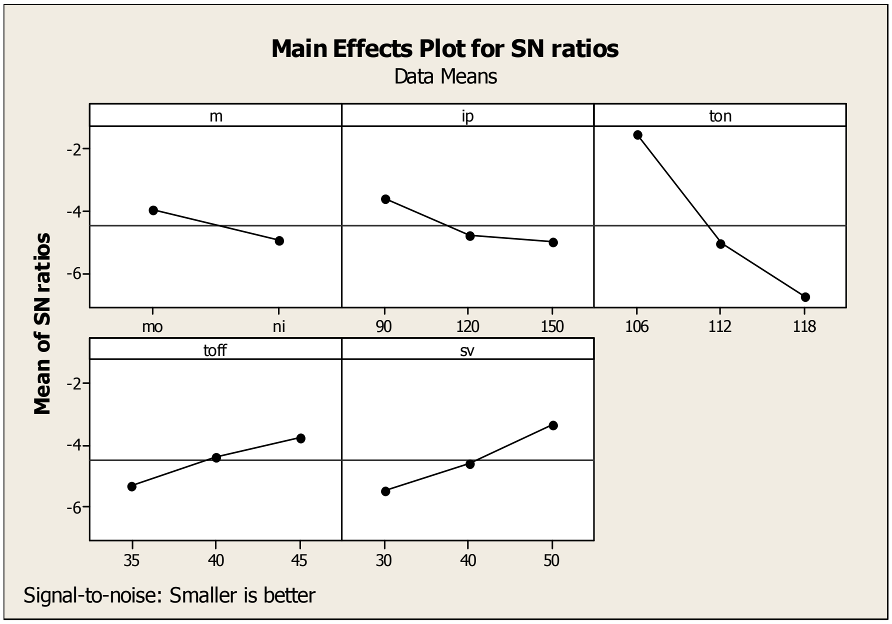

Figure 3. Main Effect Plots for S/N Ratio of Mean Surface Roughness.

3.1 Analysis Of Variance (ANOVA)

Using Mini Tab 16, a stastical tool the Analysis of variance (ANOVA) is performed to find out the significant process parameters on SR. Table 6 shows the effect of individual machining parameters (with percentage of contribution). P value lower than 0.05 implies that parameter is highly significant under 95% confidence level.

Analysis of variance (ANOVA) is employed to determine only significant parameters in order to predict the optimal values of the machining characteristics. The optimal values are calculated by using the formula.

η_{opti} = M + $\sum_{i=1}^{m}(M_{i,j})_{max} - M)$

η_{opti} = Predicate optimal value

M = Total mean of S/N ratio

m = number of significant process parameters affecting the machining performance

$(M_{i,j})_{max}$= S/N ratio of optimum level i of parameter j

Table 6 shows ANOVA for mean surface roughness. It is clear from the Table 6 all these parameters has significantly (since *p-value* ≤ 0.05) affecting the Surface Roughness under 95% confidence level. Using Eq. (2), the optimum value is calculated as follows,

η_{opti} = M + $\sum_{i=1}^{m}(M_{i,j})_{max} - M)$= 1.747 +(1.607 – 1.747) + (1.600 – 1.747) +(1.213 – 1.747) + (1.618 – 1.747) +(1.542 – 1.747) = 0.70

Table 6 ANOVA for mean surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
WM	1	0.33561	0.35561	0.35561	102.29	0.000
Ip	2	0.20028	0.20028	0.10014	28.81	0.000
Ton	2	3.02554	3.02554	1.51277	435.16	0.001
Toff	2	0.24314	0.24314	0.12157	34.97	0.002
SV	2	0.48858	0.48858	0.24429	70.27	0.002
Error	8	0.02781	0.02781	0.00348		
Total	17	4.34096				
S = 0.05896 R-Sq = 99.36% R-Sq(adj) = 98.64%						

Confirmatory experiments are conducted for SR corresponding to their optimal setting of process parameters to validate the used approach. Table 7 displays the predicted and experimental values of surface roughness.

Table 7: Optimal values of individual machining characteristics

Machining Characteristic	Optimal parameters combination	Predicted optimal value	Experimental value
Surface Roughness	A1B1C1D3E3	0.7 µm	0.8 µm

4. CONCLUSIONS

In this study, machinability of Nimonic 90 and Monel 400 with WEDM has been investigated in term of surface roughness**.** Taguchi's design of experiment techniques is used to optimized the four process parameters namely Ip, Ton, Toff and SV to achieve minimum surface roughness. The best predicated value for SR is 0.7 µm. On the basis of result, Taguchi's design of experiment technique is employed to optimize the process variables to achieve minimum SR. ANOVA is used to predict the significant factors affecting the SR. Using ANOVA on experimental results, all of these process parameters namely pulse on time, pulse off time, peak current and servo voltage are found the most significant affecting the SR under 95% confidence level. SR increases with increasing discharge energy for both work materials. Due to the difference in values of thermal conductivity of both work materials, Monel-400 has a low value of surface roughness as compared to Nimonic 90 for same discharge parameters. Confirmatory experiments show that, using present approach, process parameters are successfully optimized for minimum SR.

With increase of discharge energy results increase of surface roughness of machined surface. Surface finish of nickel based alloys significantly affects the fatigue life of machined aerospace components. The machining parameter Ton, Ip are the main factors that affects the surface roughness of the work material. Machining of Nimonic-90 and Monel 400 with WEDM at optimized setting proves the potential of WEDM in aerospace industries for machining complex and intricate shapes in hard and exotic materials.

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